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PL-TR-92-2333
Environmental Research Papers, No. 1114

PREDICTING LIGHTNING EVENTS IN THE KSC AREA: A FEASIBILITY STUDY USING SINGLE STATION DATA

Robert O. Berthel

8 December 1992

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	8 December 1992	Scientific Interim

4. TITLE AND SUBTITLE

Predicting Lightning Events in the KSC Area: A Feasibility Study Using Single Station Data

5. FUNDING NUMBERS

PE: 62101F
PR: 6670
TA: GX
WU: 12

6. AUTHOR(S)

Robert O. Berthel

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Phillips Laboratory/GPAA
29 Randolph Road
Hanscom AFB MA 01731-3010

8. PERFORMING ORGANIZATION REPORT NUMBER

PL-TR-92-2333
ERP, No. 1114

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Surface observations and early-morning radiosonde measurements, taken on a regular daily basis in the KSC area during a late summer period, were scrutinized in an effort to form a correlation with subsequent lightning related activity. Wind directions were the only measurements that could be directly associated. This study revealed that lightning activity, other than that associated with large-scale storm systems, developed in the 12-hr period following the morning radiosonde when both surface and upper-air (averaged between the 600-800 mb pressure levels) winds had directions that brought air off the ocean and moved it over land towards KSC. The most basic explanation is the advection of oceanic water vapor, the elevation of the moisture through convergence and the transport of that moisture to KSC by upper-air winds. This premise was supported by the evidence of days having no lightning activity, presumably caused by the lack of advection and/or convergence or from elevated moisture being carried away from KSC. This investigation concludes that there is a good probability that the occurrence of daytime lightning-related activity, local to the general KSC area, may be predicted from knowledge of the late-night to early-morning surface and upper wind directions.

14. SUBJECT TERMS

Lightning	Prediction	KSC
Thunderstorms	Wind direction	Kennedy Space Center

15. NUMBER OF PAGES 32

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

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1. INTRODUCTION

The potentially hazardous effects of lightning are continual threats to lives and property. For these reasons, there have been numerous innovative devices and techniques developed in recent years for the detection and/or prediction of lightning.[1]

One of the newer methods is the Artificial Neural System, which is, essentially, an artificial intelligence process that makes predictions based on similarities of existing meteorological conditions to those from days of known lightning activity.[2,3] Although complicated and computer intensive, this may be a logical approach to the problem since the building of cumulonimbus clouds (Cb) and their associated thunderstorms are dependent upon sufficient amounts of energy and moisture.

This raises the possibility that a simpler analysis of one or more of the meteorological measurements taken daily at a specific location may allow prediction of atmospheric electrical activity. This report describes an investigation of that possibility where measured meteorological parameters are correlated with subsequent weather events to evaluate predictive potentials.

2. PREDICTION REQUIREMENTS

Any lightning prediction method is required to forecast atmospheric electrical activity including both cloud to ground (c-g) and cloud to cloud (c-c) discharges. To be truly effective, it should also predict electrified cloud situations that may discharge upon aircraft or rocket penetration. The method may be long range for planning purposes or short range for immediate decision making.

Current efforts in lightning prediction are largely based on detection, and warning times vary depending upon method or methods being used. The longest times are given by optical, audio and electromagnetic systems that respond to lightning activity at far distances and the shortest, by visual tracking combined with systems designed to detect electrified clouds overhead. However, many of these techniques are based on the detection of c-g discharges. In thunderstorms, where c-g strikes are evident, c-c discharges may be expected to occur simultaneously. In situations where c-c activity may be present without c-g, many of these techniques will fail to warn of hazardous conditions for air operations.

(Received for publication 7 Dec 1992)

The movements of large air masses and associated clouds and thunderstorms are well scrutinized by established weather forecasting and, in most cases, fairly accurate, long-range predictions can be made. It is highly unlikely that any simplified analytical method could substantially improve forecasts in those scenarios. Forecasting the development of small, localized threatening cloud formations and thunderstorms, on the other hand, is extremely difficult. Thus, there is a need for a prediction scheme that could forecast those situations within a reasonable probability.

3. DATA SELECTION

Florida, being a peninsula of relatively flat terrain and high temperatures, has a meteorological history of considerable cloud activity with frequent thunderstorms. That fact, coupled with the activities at the Kennedy Space Center (KSC), makes lightning prediction particularly important in that geographical area.

Most of the numerous Florida weather studies conducted in past years have concluded that cloud, rain, and electrical storm events are related to existing synoptic situations. Thus, the prediction of lightning requires the identification of those components of the synoptic picture that may indicate future activity. To accomplish this, all available meteorological information has to be associated with subsequent events. Since the object of this investigation was to establish the feasibility of making predictions from single station data, input information was limited to that taken on a normal, daily basis within the KSC area. This narrowed the data base to the routine surface observations and upper-air radiosonde measurements.

Other limitations were imposed to make this study more manageable. It was judged that an effective warning of impending lightning should be more crucial for the hours of daylight during the times of maximum activity at KSC. This established the routine, morning radiosonde measurements as the most logical source of data, as they would provide standard meteorological information at specified atmospheric pressure levels that defined the state of the atmosphere before the disruptive effects of daytime heating. Existing weather conditions following the radiosonde balloon flights could then be defined from normal surface observations. From those data sources, a "cause and effect" relationship might become evident.

It was decided that this investigation would focus on the same summer period as that from a much more extensive Air Force study conducted by V.G. Plank[4] on the cumulus cloud and associated meteorological and rainfall events of the Florida peninsula for 19 days in August and September, 1957. That work was essentially a cloud photoreconnaissance correlated with numerous other measurements and observations and is an excellent state-wide meteorological reference source for that time period in contrast to this specified area study. Unless undetected climatological changes have occurred, Plank's data should be as pertinent today as they were 35 years ago.

A request was thus submitted to the USAF Environmental Technical Applications Center (ETAC) for copies of available meteorological surface observations and upper atmosphere data spanning the days sampled by Plank for the area now occupied by KSC.

4. DATA DESCRIPTION

Good copies of the weather observations from Patrick AFB and adiabatic charts from Cape Canaveral were received for 8 August through 7 September, 1957. Although data from these two sources do not exactly fit the criteria for single station measurements, the stations are sufficiently close to one another so that they may be considered representative of the KSC area.

4.1 Surface Observations

The surface observations from the 31 days were classified into 4 categories of potential threat of lightning related activity. The times a particular threat was noted were then listed for each day. In the few cases where more than one category was reported in the same time period, the most hazardous condition took precedence and was the one listed.

The most threatening lightning related situation was the observation of thunder that signified that a atmospheric electrical discharge had occurred within an approximate distance of 25 km.[5] No effort was made to delineate between a thunderstorm overhead or one at a distance. In either case, the storm would be close enough to be potentially hazardous. This category will hereafter be referred to as "T".

The second most threatening situation, category "L", was a report of lightning not accompanied by thunder. In most cases, this would indicate a thunderstorm in progress at some sufficiently large distance that the thunderclap was inaudible. Distances to these occurrences are normally considered to be in excess of 25 km but vary widely depending on the time of day and atmospheric visibility.[5]

Less threatening is the sighting of Cb cloud formations with no apparent lightning, labeled category "Cb". Such clouds, whether in the initial stages of thunderstorm development or dissipating remains, may contain charged pockets that may be triggered by aircraft or rocket penetration.[6]

The least threatening would be category "Cu", a sighting of towering cumulus (Cu) formations. Although these clouds pose little hazard from electrical discharges, they do indicate a vertical movement of moist air that may result in Cb development and lightning.

Classifying the observations produced statistics that characterized the late 1957 summer weather in the KSC area. Out of the 31 days, T was reported on 14, with 3 days having more than 1 occurrence. The classification of the other categories showed that L was listed on 18 days, with 10 having more than 1 occurrence; Cb had 19 and 8; and Cu, 21 and 10 respectively. Five days had no reports in any of the four categories. Although periods of rain were not categorized, it may be of interest to note that 19 days had at least one occurrence of rain. Table 1 lists the number of days each category was observed during specified 4-hr time periods. In this accounting, all observations that bridged adjoining 4-hr segments were counted as appearing in both.

Table 1. Number of Days from the 31 Day Sampling Period That Each Hazard Category Was Observed During Specified 4-hr Segments

	Category			
Time (EST)	T	L	Cb	Cu
0000-0400	3	10	0	0
0400-0800	1	4	10	8
0800-1200	1	1	6	9
1200-1600	8	4	9	13
1600-2000	8	8	13	8
2000-2400	2	13	1	0

Although maximum counts of T appear in the afternoon and evening hours as expected, L has more counts at night between 2000-0400 (all times herein are EST) probably because of the relative ease of detecting distant light flashes during hours of darkness. In contrast to this, both Cb and Cu have few or no counts during those hours, which may reflect the difficulty of identifying those cloud formations in darkened skies.

4.2 Radiosonde Measurements

Out of the possible 31 days, 29 had usable data from the early-morning radiosondes with 10 August having no morning flight and 4 September, no wind information. Unfortunately, both missing days experienced thunderstorms.

Nineteen days had balloon launch times listed at 0630 with 2 days being earlier by 4 and 26 min. Of the 8 days with launches later than 0630, 7 were prior to 0700 with the latest at 0734 on 31 August.

5. DATA ANALYSES

5.1 Numerical Hazard Rating

A numerical rating system was devised to describe the degree of hazard from lightning related activity that existed within specific time periods to enable comparisons of potential threats among different days. The length of time in hours a threat was observed, multiplied by a hazard factor particular to that category, produced a numerical value. A summation of values from the four categories over a specified time period gave the numerical rating. The hazard factors used for T, L, Cb and Cu were 10, 5, 1 and .5 respectively. Thus, T was defined as being twice as hazardous as L, 10 times that of Cb and 20 of Cu.

The daily numerical rating for the time periods of 1300-1900 and 0700-1900 are shown plotted in Figure 1. The days experiencing daytime lightning activity are marked by *'s. It is evident from these plots that the major portion of hazardous activity occurred in the afternoon hours.

5.2 Surface Data

The early-morning surface or ground-level measurements of temperature, pressure, relative humidity, and wind were compared with the numerical ratings in an attempt to match specific conditions with lightning related activity

Two sets of surface data were supplied by ETAC, the observations from Patrick AFB and the more northerly radiosonde measurements from Cape Canaveral. The times of the radiosonde flights however, were mostly incompatible with the hourly observations. Therefore, the values for the Patrick surface data listed herein were from the nearest hourly time to that of the radiosonde or from averages of the before and after hourly readings. In general, the two sets of values agreed fairly well, with few differences noted, as would be expected, since the sites are only separated by approximately 30 km.

5.2.1 PRESSURE

Figure 2A shows the daily surface pressure measurements in millibars (mb) as recorded at the two sites. The data sets are quite comparable with the largest discrepancy being 2 mb on 12 & 17 August. When compared to Figure 1, it is obvious that the pressure fluctuations do not correlate with the numerical hazard ratings.

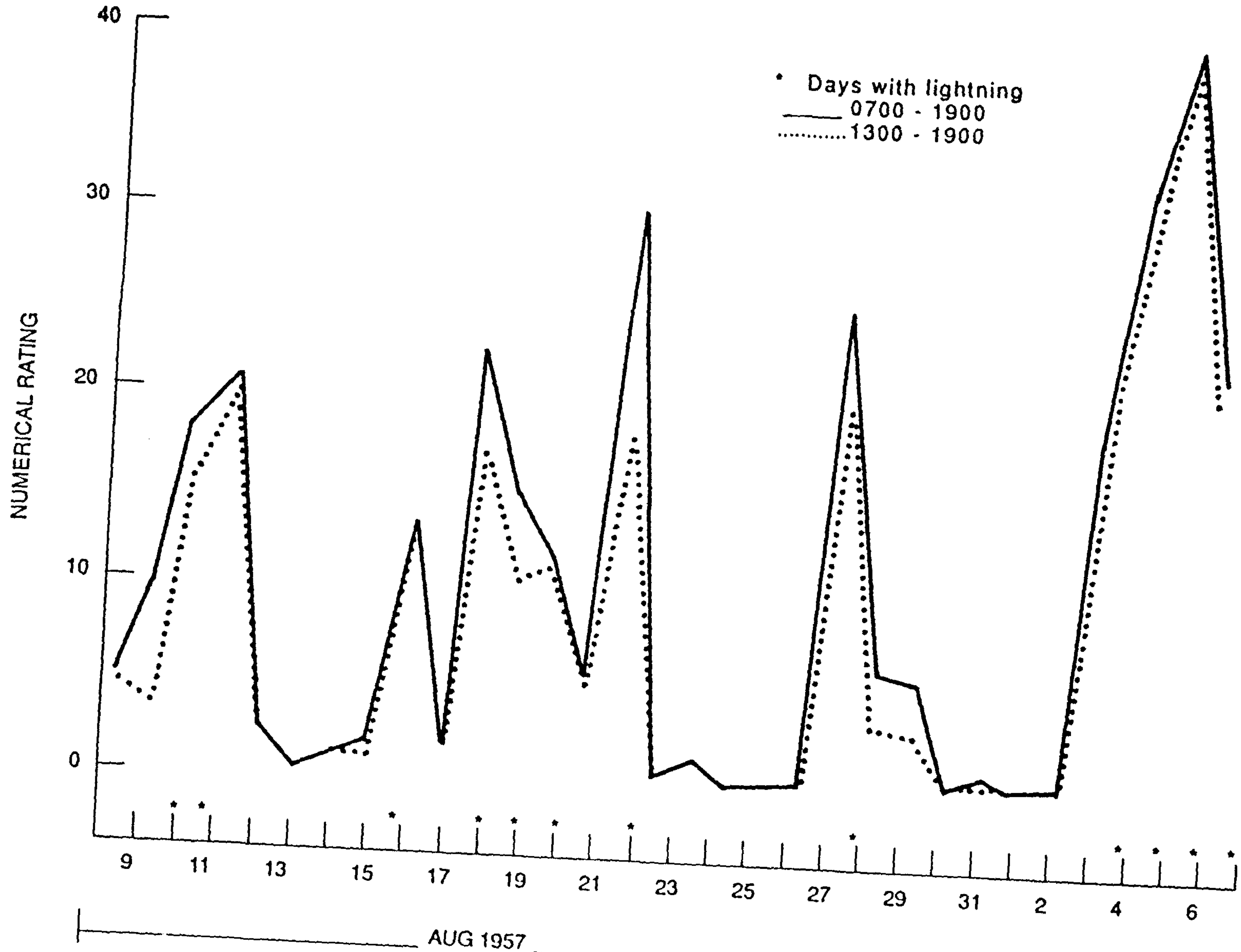

Figure 1. A non-dimensional numerical rating of daily lightning hazards. (NR = hrs x hazard factor — see text for details)

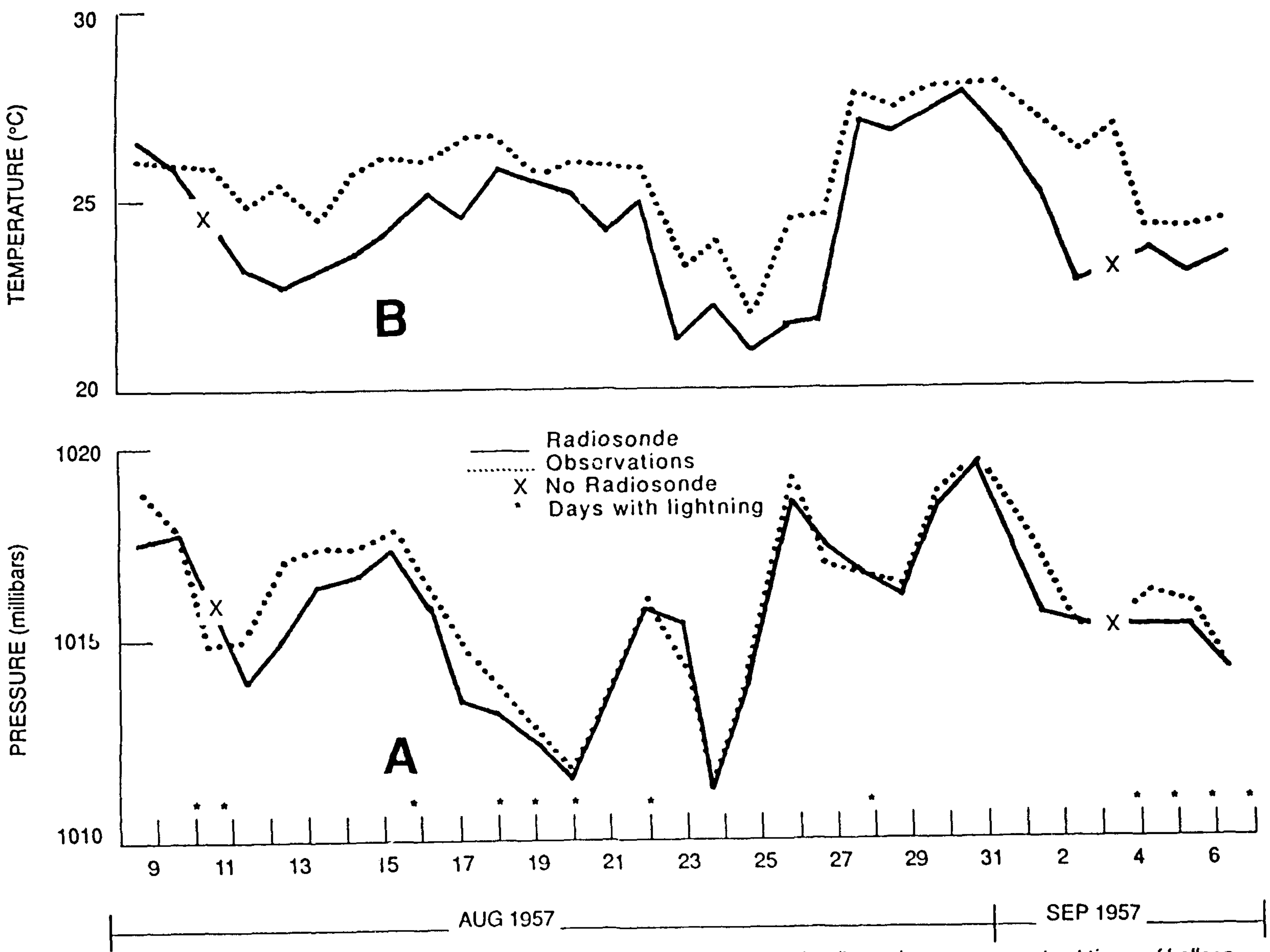

Figure 2. Daily surface temperatures and pressures from observations and radiosonde measurements at times of balloon launch.

5.2.2 TEMPERATURE

Figure 2B shows the daily surface temperatures recorded at the 2 sites. The readings from Patrick are generally higher with 4 days (12, 26, 27 August and 3 September) showing notable differences of ~ 3° C. It is also evident that the early-morning surface temperatures have no direct correlation with the numerical ratings.

5.2.3 RELATIVE HUMIDITY

The surface relative humidities from both sites are shown in Figure 3A. The radiosonde measurements are generally larger than the observations with notable differences of 12 to 16 percent on 11, 26, 27 August and 2, 3 September. Again, there is no apparent correlation with the numerical ratings.

5.2.4 WIND

The plot in Figure 3B shows both recorded wind speeds that are, for the most part comparable, with differences of 2 to 3 m s^{-1} noted on 19, 20, 31 August and 1 September. Also, there are 5 days where the radiosonde data listed calm conditions. The surface wind speeds at the times of balloon launch do not seem to give any indication as to future lightning activity.

The wind directions, for Patrick AFB and Cape Canaveral as plotted in Figure 4, are very similar except for 24 August. (Surface observations recorded an abrupt shift in wind direction in this time period.) The values of the observations were estimated in increments of 22.5° from the symbols on the observers logs. Of the 12 days experiencing lightning activity between 0700-1900, 11 have directions between ~ 170° and ~ 292°. This is the first hint, however tenuous, of a relationship between the morning meteorological measurements and subsequent lightning hazards.

5.3 Atmospheric Measurements

As mentioned previously, there were 29 days with usable radiosonde data. Information obtained from each balloon flight consisted of measurements of altitude, relative humidity, temperature, wind direction, and wind speed at specified standard atmospheric pressure levels. Sporadic dew point readings negated the use of those measurements for daily comparisons. Each day's data were analyzed in an attempt to identify characteristics common to the days of lightning activity.

5.3.1 PRESSURE

Values of pressure were derived for various altitudes between ~ 600 to ~ 8600 m in the search for a correlation with the numerical ratings. Only subtle pressure changes between altitude levels were noted similar to those in the plots at the three levels shown in Figure 5.

5.3.2 TEMPERATURE

Temperatures were also calculated for the same altitude levels as that of the pressures. More pronounced changes between levels were evident, as shown in Figure 6 but no relationship with the numerical ratings was evident.

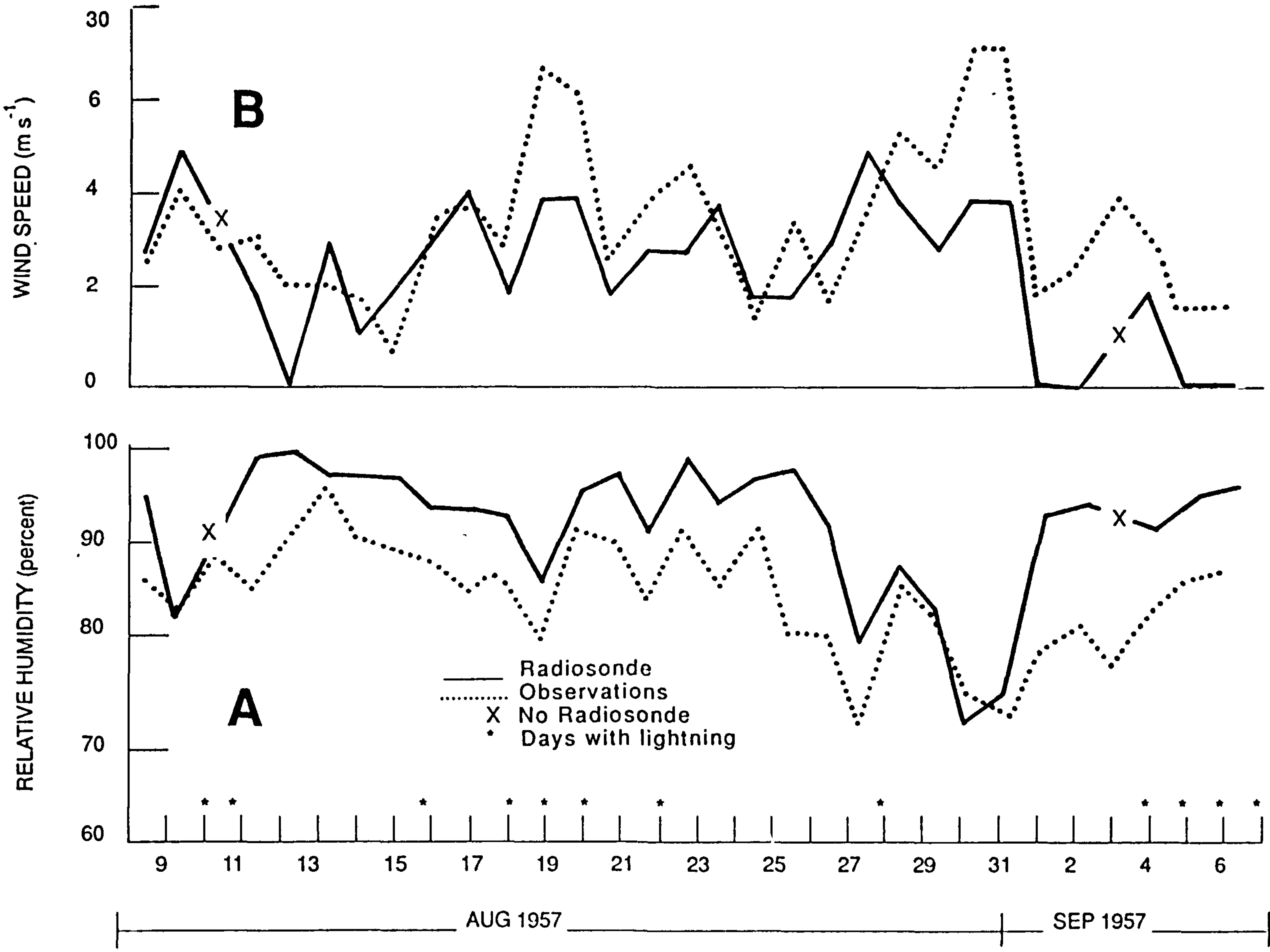

Figure 3. Daily surface relative humidity and wind speed from observations and radiosonde measurements at times of balloon launch.

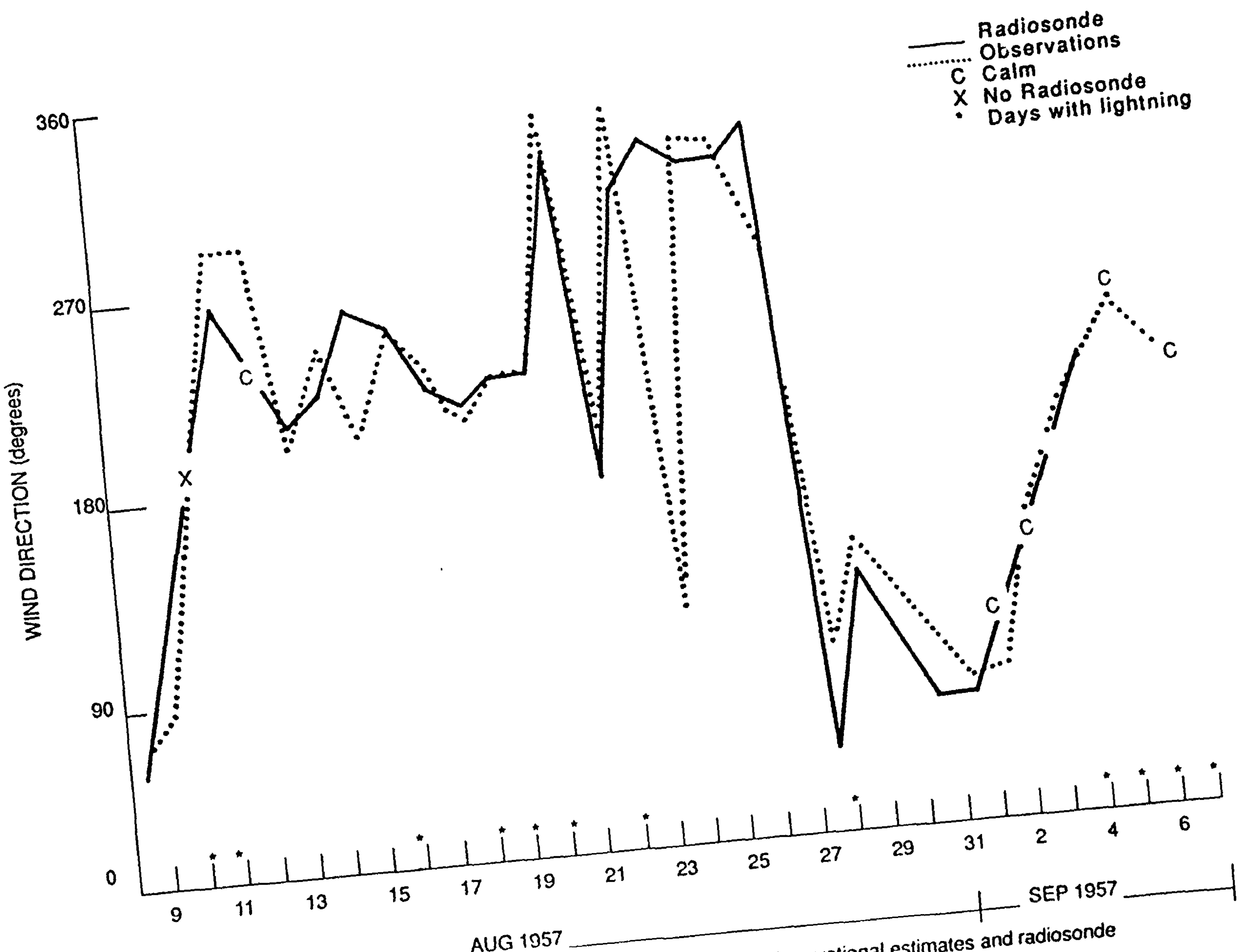

Figure 4. Daily surface wind directions at times of balloon launch from observational estimates and radiosonde measurements

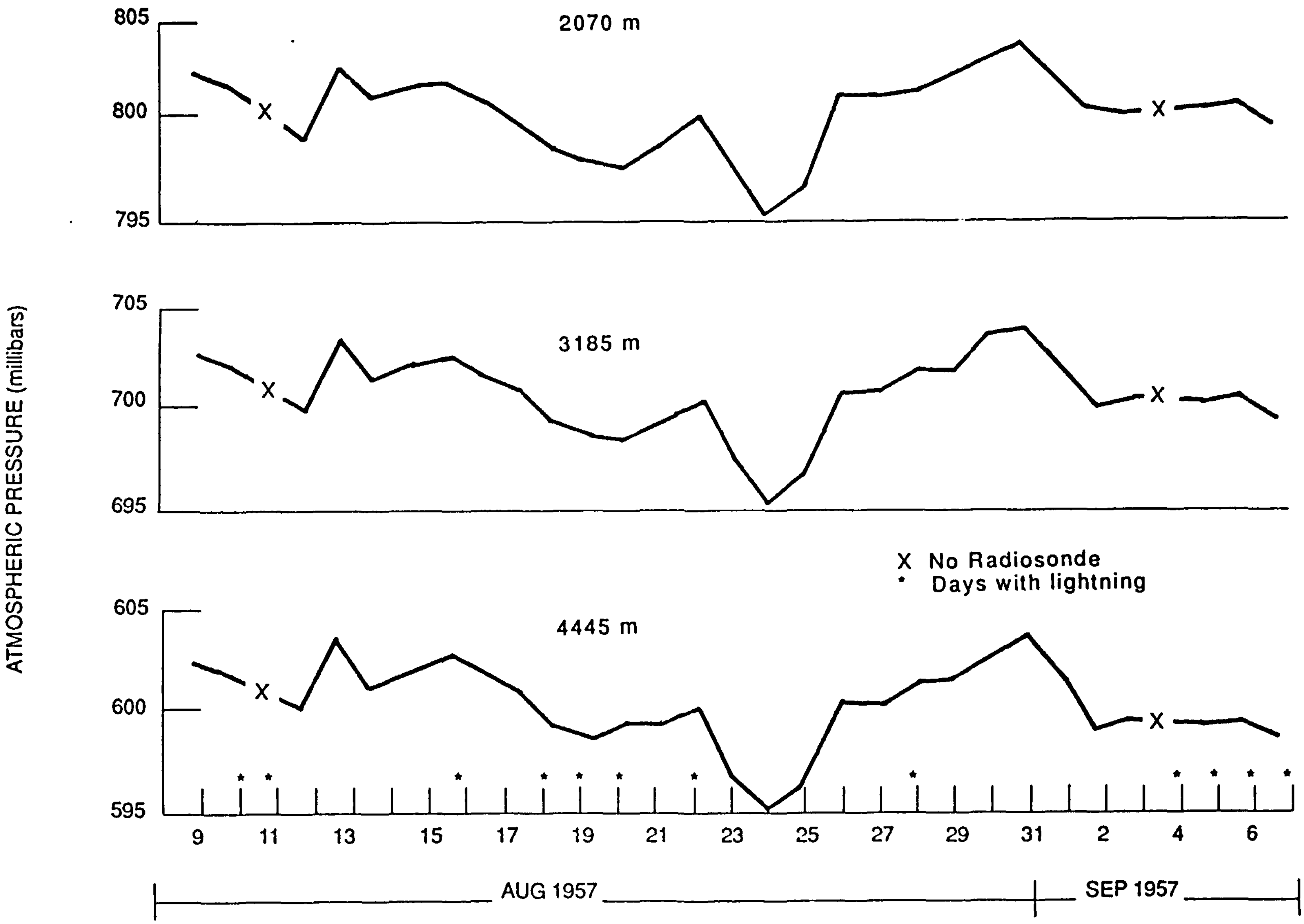

Figure 5. Daily pressure measurements at three altitude levels for the 29 days with radiosonde data.

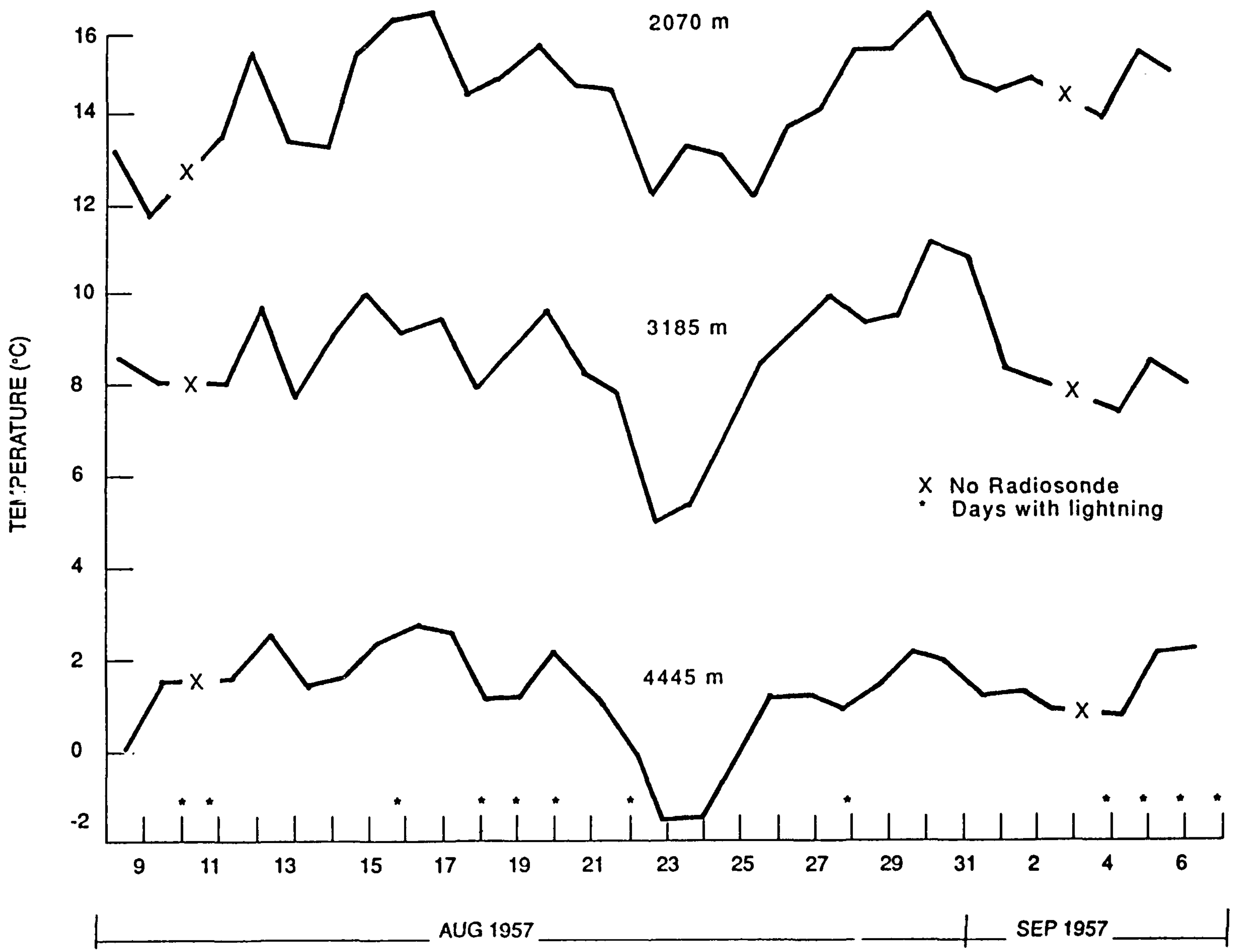

Figure 6. Daily temperature measurement at three altitude levels for the 29 days with radiosonde data

5.3.3 ATMOSPHERIC STABILITY

Instability in the upper atmosphere is often cited as a precursor to thunderstorms due to the upward movement of warm, moist air. This may be particularly true during thunderstorm development and may even be detected in the initial building of Cb formations. It is however, questionable as to how long before the advent of lightning atmospheric instability would be evident.

Plank, in his report (Table 8), listed calculations of stability for four cloud-rain situations based on wind speed and direction using radiosonde data from four stations throughout Florida. He found no significant differences in stabilities between situations.

Atmospheric stabilities were derived for three distinct hazard scenarios from the Cape Canaveral data in this investigation. The first was composed from 10 days where the hazard categories of T and L were reported in the 12 hrs following radiosonde launch. The second was composed from 6 days where only Cb and Cu were listed and the third, from 6 days of no lightning hazards during that time. Table 2 lists the stabilities calculated from the radiosonde altitude and temperature information for the same levels as reported by Plank. The associated standard deviations are included as indicators of the prevailing scatter of the data at each level.

In accord with Plank's results, the stabilities listed in Table 2 show insignificant differences except for the first level where large data scatter existed. Thus, the morning atmospheric stabilities do not seem to be good indicators of future, daytime lightning activity.

Table 2. Atmospheric Stability Between Specified Pressure Levels For 10 Days With T & L, 6 Days With Cb & Cu and 6 With No Hazards in the 12 hrs Following Radiosonde Launches

Pressure Level	T & L		Cb & Cu		No Hazard	
	Stab	SD	Stab	SD	Stab	SD
mb	Δ(°C km^{-1})		Δ(°C km^{-1})		Δ(°C km^{-1})	
sfc-1000	3.0	6.8	2.3	8.0	13.0	8.7
1000-850	-5.4	0.5	-2.1	1.0	-6.0	0.9
850-700	-5.6	0.5	-2.1	1.0	-4.9	1.1
700-500	-5.4	0.6	-5.7	0.4	-5.7	0.5
500-400	-6.5	0.7	-6.6	0.7	-7.0	0.5
400-300	-7.4	0.4	-7.3	0.6	-7.7	0.4
300-250	-8.5	2.3	-8.9	0.8	-8.4	1.8
250-200	-7.8	0.8	-7.8	0.6	-7.1	0.9

5.3.4 RELATIVE HUMIDITY

Figure 7A shows the daily, average relative humidity contained in the first 3000 m of air above ground level at the times of the radiosonde flights. There is a slight correlation with the numerical ratings in that all days with lightning activity had averages of 70 percent or better although other days with little or no hazards also had high readings. The lowest value was just under 60 percent on 25 August, which points to a common availability of reasonably moist air during the Florida summer even at the morning sampling times before the effects of midday heating.

5.3.5 WIND

The above ground wind information was determined from averaged radiosonde measurements between the 600 and 800 mb pressure levels. The lower limit of 600 mb was chosen, because the wind fields on most of the days showed abrupt changes in directions and speeds at lesser pressure or higher altitude levels. The upper limit of 800 mb was selected because a number of cases exhibited shifts in wind directions that seemed related to surface wind in the higher pressure or lower altitude levels. Thus, that segment of the atmosphere was the most stable for the 29 days used in this study. The mean altitude and temperature values at 600 mb were 4443 m and 1.2°C and 2068 m and 14.1°C at 800 mb. Winds within the 600-800 mb atmospheric pressure limits will be referred to as upper winds to make a clear distinction with those at ground or surface level.

The averaged upper-wind speeds are plotted in Figure 7B. Once again, there is no apparent correlation with lightning related activity.

The upper-wind directions however, have a similar relationship with the days of lightning as the surface measurements. The solid line in Figure 8 is a plot of the daily averaged, upper-wind directions and the dotted line is the superimposed surface radiosonde values from Figure 4. The days where calm conditions were recorded by the radiosonde were filled with the estimated values from the surface observations. Other than 28 August, all days with lightning had both surface and upper-wind directions between ~ 170 and 292°.

6. DISCUSSION OF WIND EFFECTS

Wind has long been recognized as possibly being the most influential factor in the building of cumulus clouds over Florida. In his 1965 report, Plank cited work performed in the 1940's[7,8] where Florida cloud and rain situations were related to wind effects. Plank also discussed the peninsula-wide relationship of different wind regimes and cloud development. More recent work by Lopez, et al. (Reference 9) has associated wind fields with lightning over South Florida.

Out of the 29 days with morning radiosonde data used in this study, 10 had lightning activity during the 12 hr following the radiosonde flights. Nine of those had measurements showing both surface and upper-wind directions between ~ 170-292°. These findings are in accord with those of Lopez and Holle[10] where mean low-level wind directions were found to relate to lightning in Central Florida. In fact, the ~ 170-292° directional zone from this study essentially includes their most active 90° sector of 203-293°.

This investigation also revealed that 6 other days had only upper-wind measurements within 170-292° with 5 more having only surface winds within those limits. None of those 11 cases experienced daytime lightning activity. The remaining days of the data set had both surface and upper-wind directions generally from the NE to SE. Just one of those days had daytime lightning.

Plank cited five basic factors responsible for the convective cloudiness and rainfall of the Florida peninsula with the three most important being wind related:

"1. The daily variations in the low-level advection of water vapor into the interior regions of the peninsula from off the oceanic surroundings — —,

2. The daily variations in the transport of pre-existing cloud populations and cloud systems, into the peninsula from off the oceanic area upwind of the peninsula — —,

3. The daily variations in the low-level convergence associated with the orographic barrier effect of the peninsula. This convergence, a component of the total low-level convergence, is visualized as arising from the pen-

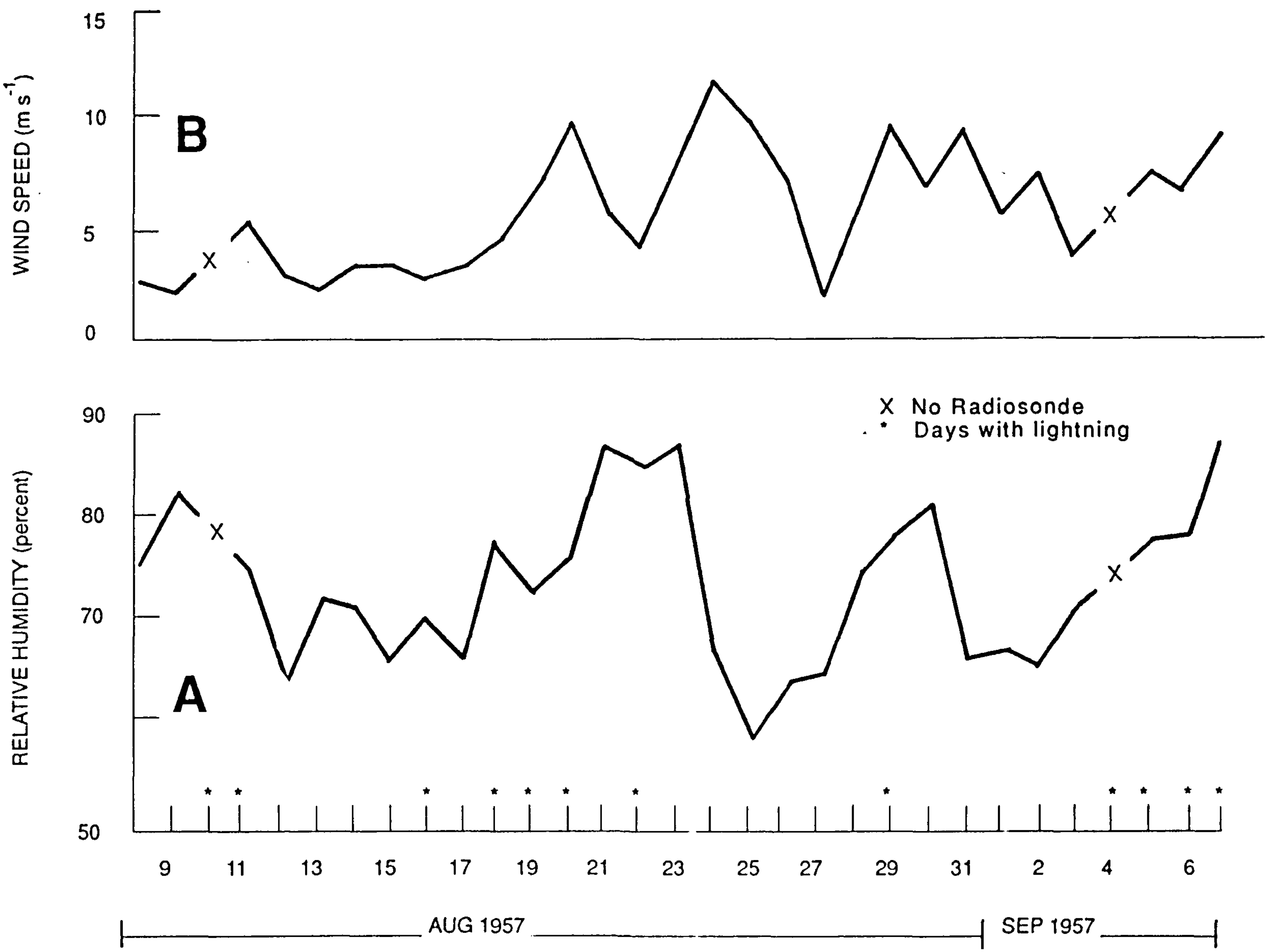

Figure 7. Daily relative humidity averages from surface to 3000 m and average wind speeds between the 600 and 800 mb pressure levels from the 29 days with radiosonde data.

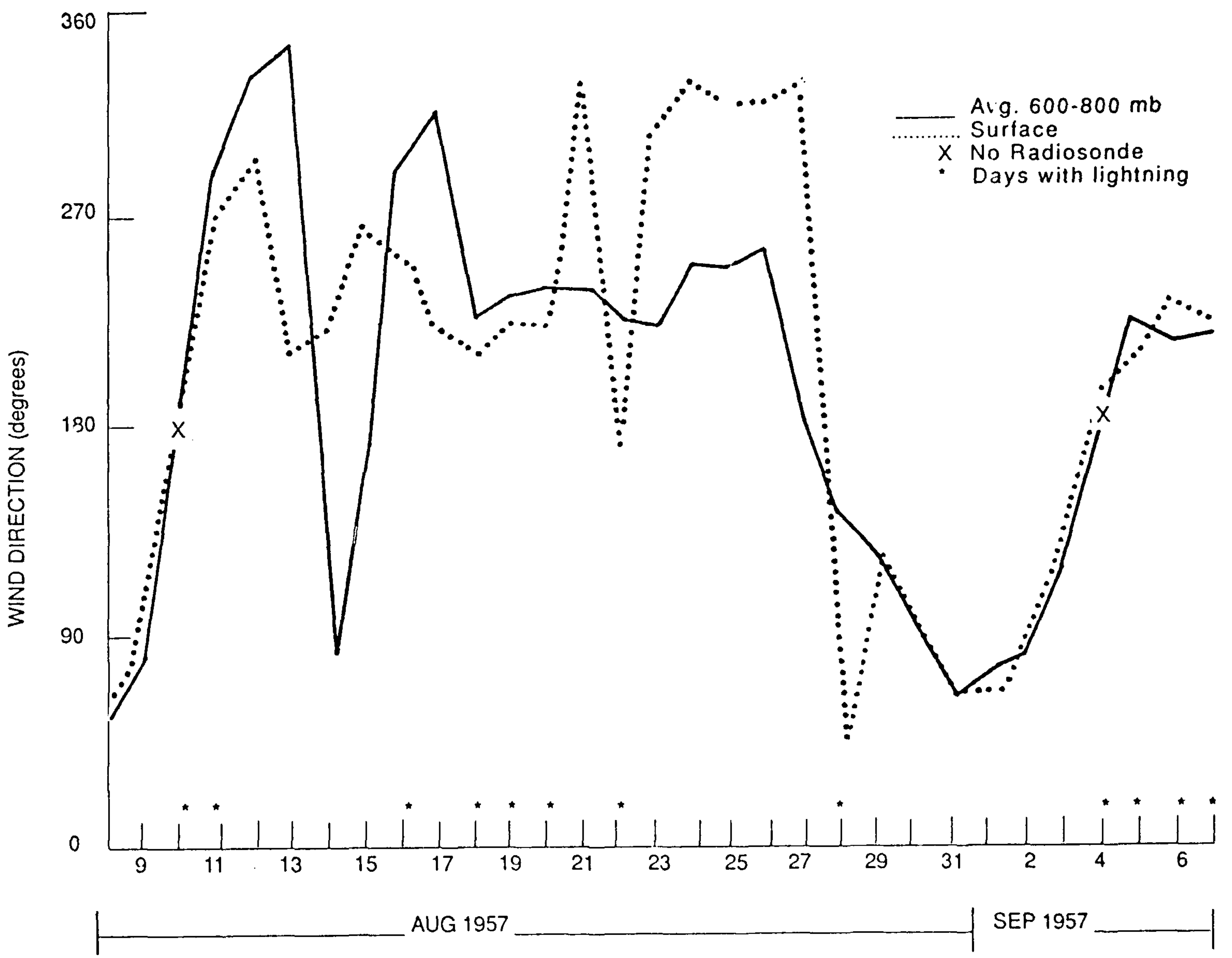

Figure 8. Daily wind directions averaged between the 600 and 800 mb pressure levels with superimposed surface values from Figure 4.

insula, in its ~tirety, acting as an impediment, or partial barrier, to the free flow of the Florida area winds across the peninsula. — —".

Factors #1 and #3 are associated, at least in part, with the effects of the low-level winds on the supply of available water vapor and the lifting of that moisture into the atmosphere. The subsequent movement of the elevated moisture is then dependent upon the characteristics of the upper winds. Factor #2 is associated only with upper winds and, since it involves the on-shore movement of pre-existing cloud systems, it is presumed that a factor #2 situation is one that would be readily predicted by normal forecasting.

Plank's factors however, were determined for general cloud and rain situations and are not specific to thunderstorms. Additional energy is required to account for the vertical movement of large amounts of moisture upward into the atmosphere for Cb development. That energy is readily available in large-scale storm systems or frontal movements. Localized thunderstorms most likely obtain the added energy through daytime heating in concert with surface-wind (including sea-breeze) effects.

6.1 Upper Winds

The measurements from the 29 days with morning radiosonde data were examined, using the premise of upper-wind transport and Plank's wind dependent factors, to explain the apparent relationships of wind directions and daylight lightning events in the KSC area that were found in this study. The same rationale was applied to the days without lightning activity to explain why lightning did not occur. As wind directions were the prime considerations in those examinations, a perspective of the significant directions relative to KSC is helpful. These are shown in the map of the Florida peninsula in Figure 9 where the directions within ~ 166-299°, that include the majority of cases in this study, are off the ocean and travel over land on a path to KSC. The directions within the arc extending from ~ 299-334° are only from land whereas those from the ~ 334-166° directions are only from the Atlantic Ocean.

The 29 days with usable radiosonde data were separated into three groups according to upper-wind directions. On 11 days, averaged, upper winds were from 61-160° (ocean), on 3 from 309-331° (land) and on 15 from 179-287° (ocean/land).

Wind-direction scenarios were made under the presumption that the upper winds measured by the morning radiosondes were integral parts of the prevailing synoptic situations, thus they were representative of those within a large general area surrounding KSC. Those winds however, were required to have existed for sufficient time to account for the possible movement of moist air to or away from KSC. Some information was obtained on the persistence of the wind directions by comparing the averaged value from the evening radiosonde of the previous day with the morning and evenings values obtained on a particular day. This gave the averaged, upper-wind directions at the start, middle and end of a ~ 24 hr period as listed in Table 3. Three values with little change provided reasonable assurance of a fairly constant air movement both before and after the morning radiosonde whereas, three values with substantial differences most probably signified a changing synoptic situation.

The directional stability of the upper air was also considered important as a large variability in direction within the upper winds may denote a mixing of air from different sources thereby spreading and diluting the available moisture. Information on the stability of the wind direction may be inferred from the calculations of standard deviation of the measurements within the 600-800 mb pressure levels. These are also listed in Table 3.

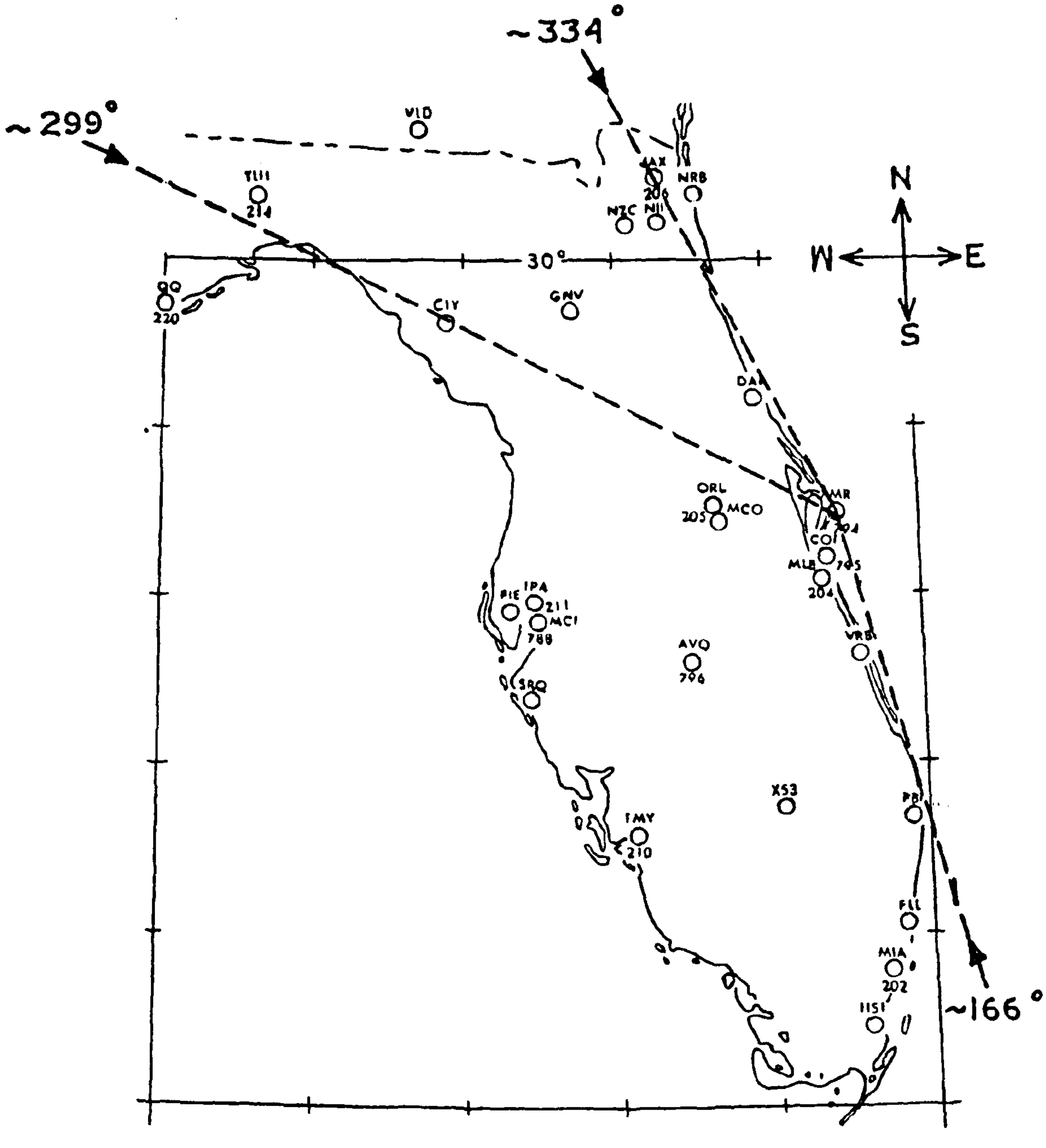

Figure 9. Map of the Florida peninsula showing the significant wind directions in relation to KSC.

Table 3. A Listing of Averaged, Upper-wind Directions and Their Standard Deviations Within the 600-800 Mb Pressure Levels From the Previous Evening, Morning and Evening Radiosonde Measurements. Dates marked with "*" experienced daytime lightning activity. The value listed for the previous evening on 11 August was from the 1300 radiosonde on 10 August. There were no radiosonde data on 4 September

Date	Previous Evening		Morning		Evening	
	Avg	SD	Avg	SD	Avg	SD
	Direction (degrees)		Direction (degrees)		Direction (degrees)	
8 Aug 57	120	27	116	19	61	5
9 " "	61	5	85	26	317	76
11* " "	276	15	285	10	306	8
12 " "	306	8	324	60	313	45
13 " "	313	45	331	45	14	23
14 " "	14	23	84	14	194	55
15 " "	194	55	160	31	259	17
16* " "	259	17	287	16	350	53
17 " "	350	53	309	48	275	9
18* "	275	9	224	15	242	9
19* " "	242	9	232	6	248	7
20* " "	248	7	236	8	261	7
21 " "	261	7	234	13	272	79
22* " "	272	79	222	23	257	25
23 " "	257	25	217	31	256	29
24 " "	256	29	243	31	244	8
25 " "	244	8	243	11	266	8
26 " "	266	8	247	6	281	31
27 " "	281	31	179	79	291	89
28* " "	291	89	135	10	108	20
29 " "	108	20	118	7	100	7
30 " "	100	7	85	5	56	13
31 " "	56	13	61	5	56	6
1 Sep 57	56	6	72	16	70	12
2 " "	70	12	77	9	79	22
3 " "	79	22	112	20	175	6
5* " "	—	-	215	14	229	14
6* " "	229	14	206	5	208	12
7* " "	208	12	210	13	199	7

6.1.1 OCEAN DIRECTIONS (~ 334° TO ~ 166°)

Ten of the 11 days with upper winds off the Atlantic Ocean were within 61-135°. Advection and convergence may have occurred on any or all of those days but the directions of the upper winds dictated that the moist air would have been moved inland and away from KSC. The other day had a direction of 160° that was nearly parallel to the shoreline. Since any possible convergence would have been expected to take place inland as opposed to the shore, it is assumed that the upper wind, on that day, would have carried any upper-air moisture on a NNW track inland of and past KSC. All had quite stable upper winds at the time of the morning radiosonde other than the 160° case that had moderate variability. Four days showed changing wind directions over the daylight hours with another changing during the preceding night.

One of those 11 days (28 August — 135°) however, had daytime lightning activity and seems to be contrary to the above reasoning. Plank presented (Figure 5 in his report) a series of photographs of radar echoes taken on 28 August covering the time period 0922-1549. The first showed a relatively thin cloud bank extending from NE to SW across the southern part of the Florida peninsula. By 1313, the cloud bank had expanded threefold and moved in a NW direction up into the center of the peninsula with the furthest most NE echoes being just south of KSC. This agrees with the observers notes of Cu during the mid-morning hours, L beginning at 1200, T at 1400, and a general NW movement. Both the cloud expansion and movement continued through the last photograph at 1549 where radar echoes covered most of the lower half of the peninsula. The meteorological event on 28 August, being a pre-existing, large-scale cloud system moving from the ocean into the peninsula, thus coincides with Plank's basic factor #2. As such, it is a good example of a situation that would have been readily forecasted.

6.1.2 LAND DIRECTIONS (~299° TO ~334°)

Of the 3 days with averaged upper winds from the land directions, none had daytime lightning although all experienced some Cb activity for short periods in the late-afternoon or early-evening hours. That indicates that convergence had occurred and suggests that the upper air being transported into the KSC area lacked the necessary moisture for thunderstorm development. If sufficient advection and convergence did, in fact, occur on those days, then upper-air mixing of the moist air with dryer air from the NW (land) directions may have taken place. That scenario was the most probable as all 3 days showed some instability in their upper-wind directions at the time of the morning radiosonde. Also, two of the days showed systematic changes in wind direction that signified changing synoptic conditions over the 12 hr periods before and after radiosonde launch.

6.1.3 LAND DIRECTIONS (~ 299° TO ~ 334°)

Of the 15 days with upper winds from the ocean/land directions, 9 experienced daytime lightning activity. The meteorological conditions on those days indicate that they are in accord with Plank's factors #1 and #3 in the context of advected, moisture-laden air being elevated into the atmosphere by low-level convergence and with the carrying of that moisture towards KSC by the upper winds. All showed stable upper-wind directions between 206-287° with no significant changes in the 12 hr periods surrounding the morning measurements. In addition, those 9 days also had surface winds from the ocean/land directions at the times of the radiosonde launches.

Six days had upper winds from 179-243° but did not experience daytime lightning activity. That is an indication that the air being moved towards KSC by the winds on those days lacked the necessary combination of energy and moisture for Cb development, which may have resulted from insufficient advection and/or convergence since five of those days had quite stable upper winds with very small directional changes over the 24 hr period. All six days however, had surface winds generally from the NNW to NW (land) directions as measured by the radiosondes at launch times.

Thus, the apparent singular difference between the 6 days without lightning activity and the 9 days with lightning was in the directions of the surface winds, as the upper winds were all from the ocean/land directions.

6.2 Surface Winds

The time histories of the surface-wind directions prior to daytime heating were examined on the 15 days that had upper winds from the ocean/land directions. That information was obtained from the wind direction arrows on the observers logs. Figure 10 shows the hourly, averaged directions as solid lines from 2100 (previous nights) through 0800 for the 9 days with and 6 days without lightning activity. Just 4 of the days with no lightning are included in the averages of that situation as the other 2 days, 24 & 25 August, have very different direction histories. Those 2 days are plotted separately as dashed and dotted lines in Figure 10. (The observers log for 24 August listed a thunderstorm during the very early-morning hours followed by an abrupt change in the surface-wind direction from NW t[illegible]tween 0500 and 0600. The radiosonde surface direction at 0630 for that day was 320°.) The differences in the plot [illegible] the averaged, surface winds are evident as the days that experienced lightning had directions from the S to SW throughout that time whereas the averages from the days with no lightning activity showed a change from SE to N. The 2 days, plotted separately, essentially show NE to NW wind directions. Thus, it became obvious that it was the directions of the surface winds throughout the night and early-morning hours that made the difference between the lightning and no lightning situations and not just the surface-wind directions at the times of the radiosonde launches.

The individual direction values from which the hourly averages were derived varied considerably due to natural fluctuations in the surface winds and, in part, to the estimates from the observers' symbols that recorded the directions in 22.5° increments. As a result, all but 3 of the 15 days had at least 1 reading that strayed beyond the limits of the ocean/land direction range with the 9 days that had lightning activity having more consistent directions within those limits. Another way of illustrating the differences between the two situations is by listing the mean directions and their corresponding standard deviations over the 2100-0800 time period for each of the 15 cases. Those values are listed in Table 4 and show that the 9 days with lightning had 12 hr surface-wind averages from the ocean/land directions with standard deviations of 35° or less. The no lightning situations however, show standard deviations of 70° or larger in 5 cases and 1 with a small standard deviation but with the averaged direction outside the ocean/land range.

Table 4. Averaged, Surface-wind Directions and Standard Deviations During the Night and Early-morning Hours for 9 Days With and 6 Days Without Daylight Lightning Activity in the KSC Area. All 15 Cases had Upper Winds from 179-287°.

Lightning		No Lightning	
Avg (degrees)	SD	Avg (degrees)	SD
257	35	264	87
204	34	184	105
202	18	294	108
215	15	312	7
219	10	208	79
200	32	209	70
188			
215			
200			

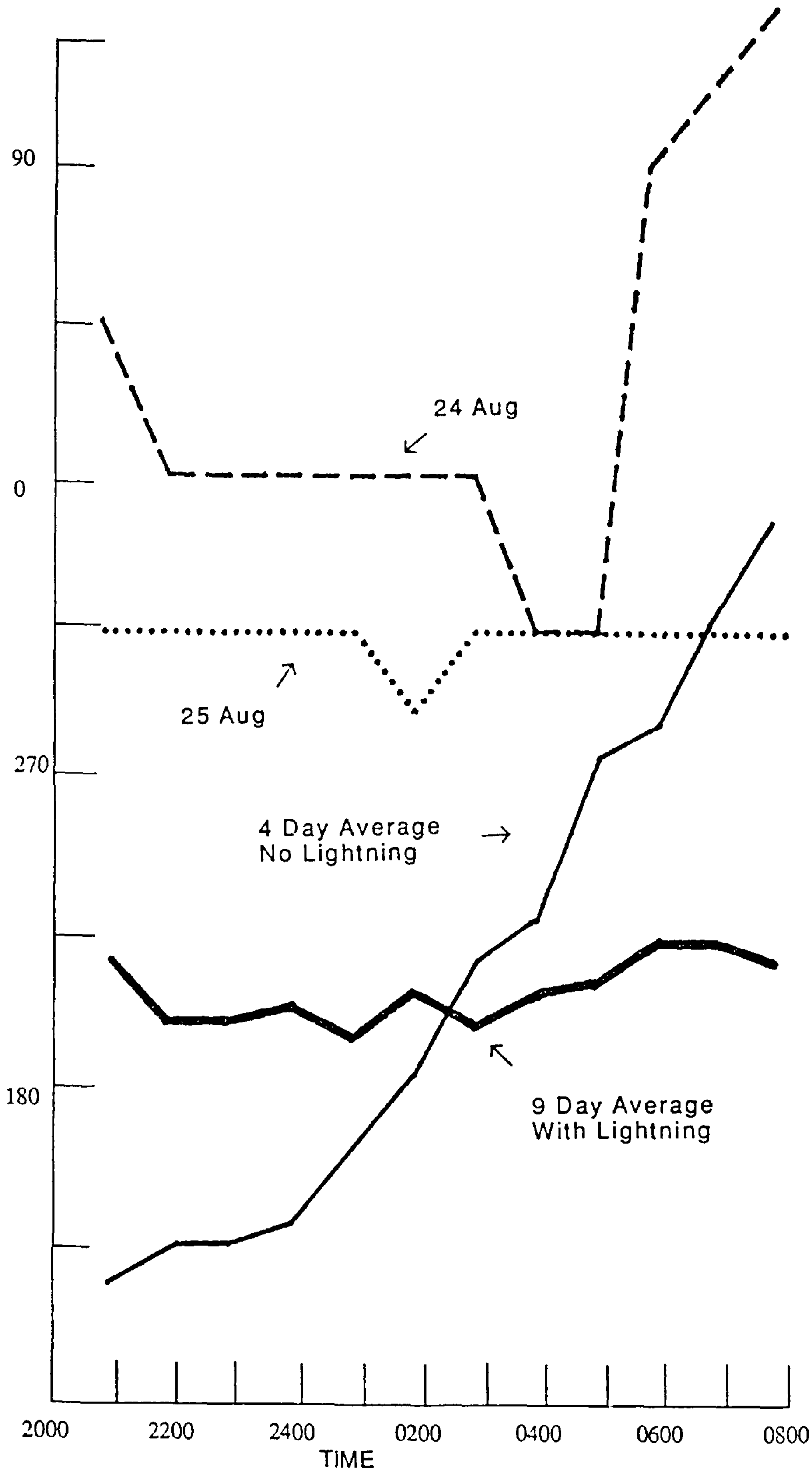

Figure 10. Night to early-morning, surface-wind direction information for the 15 days with upper-wind directions between 179-287°

The evidence presented in Table 4 and Figure 10 identifies the surface-wind directions during the night and early-morning hours as being the determining factors in the development of daytime thunderstorms when the upper winds are from a general S to W direction towards KSC. That suggests a scenario of a S-W surface-wind flow during the night and early-morning hours causing moisture-laden air to permeate the lower atmosphere, the lifting of the moisture through midday heating and the movement of that elevated moisture into the KSC area by the upper winds.

A step-by-step explanation of the meteorological processes by which the night and early-morning, surface-wind directions affect the subsequent daytime lightning activity in the KSC area is not completely obvious from the data available to this study. Presumably, it is directly associated with the advection of water vapor and atmospheric convergence (or divergence, a process opposite to convergence involving the downward movement of air that is generally attributed to the effects of nighttime cooling) that are, in turn, influenced by many other factors other than wind directions such as wind speeds, temperatures, topography, etc. A thorough investigation of this subject requires complex, detailed analyses of many measurements from several stations and is well beyond the scope of this study.

7. SUMMATION AND RECOMMENDATIONS

Surface observations and morning radiosonde measurements taken on a regular daily basis in the KSC area were scrutinized in an effort to form a correlation with subsequent lightning related activity. Wind directions were the only measurements that could be directly associated.

This study revealed that the major portion of lightning activity that developed in the 12 hr period following the morning radiosonde occurred when the upper winds, averaged over the 600-800 mb atmospheric pressure levels, and the surface winds both had directions that brought air off the ocean and moved it over land towards KSC. The most basic explanation is the advection of oceanic water vapor, the elevation of the moisture through convergence and its transport to the KSC area by the upper winds. This premise was supported by the evidence of days having no lightning activity presumably caused by insufficient advection and/or convergence or from the elevated moisture being carried away from KSC.

Thus, the results of this investigation showed that in all situations, other than those meteorological events with lightning related activity normally predicted by existing weather forecasting, the accepted basic meteorological principles of moisture advection, convergence, and upper-air wind transport may be used to explain the daytime, lightning-related activity that occurred in the KSC area when both the surface and upper winds had been consistently moving from the 170-292°directions towards KSC throughout the night and early-morning hours. That conclusion strongly suggests that there is a good probability that the occurrence of daytime lightning related activity, that is local to the general KSC area, may be predicted from knowledge of the surface and upper-wind directions. Non-local, more widespread lightning activity caused by meteorological situations such as large-scale storm systems, frontal movements etc., do not require prediction by these means as they would be readily forecasted on a normal basis.

Predicting lightning activity from wind directions as outlined above would have proven very effective if it were applied to the particular set of data used in this study. However, it falls short of being the most ideal prediction scheme as it is (a) for a large, general area and cannot predict the events for precise locations, (b) for lightning activity as a whole and cannot specifically predict overhead vs distant thunderstorms or potentially dangerous Cb formations, and (c) for an approximate 12 hr time period and cannot predict events in shorter, more useful segments (although all category T events happened to occur within 1100-1900).

But, this scheme does have, at least, one possible redeeming feature. It may be able to predict the development of local thunderstorms some hours in advance of the events on days that none may be expected and that, by itself, would prove its usefulness.

Therefore, it is recommended that other data sets be analyzed to verify the findings of this study. Seasonal conformity with this investigation should not be of concern since different, season-dependent wind fields should only affect

the frequency of thunderstorm occurrence, not the meteorological principles cited above. If the wind-direction and lightning relationships are corroborated, further investigations may then narrow the time windows in which the events are to occur by more in-depth analyses of the surface and upper-wind characteristics during the preceding night and early-morning hours.

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